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RESEARCH MEMORANDUM

for the

Bureau of Ordnance, Department of the Navy

PERFORMANCE OF SINGLE-STAGE TURBINE OF MARK 25 TORPEDO

POWER PLANT WITH TWO SPECIAL NOZZLES

II - EFFICIENCY WITH 20°-INLET-ANGLE ROTOR BLADES

By Harold J. Schum and Warren J. Whitney

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

For REFERENCE

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PERFORMANCE OF SINGLE-STAGE TURBINE OF MARK 25 TORPEDO

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II - EFFICIENCY WITH 20°-INLET-ANGLE ROTOR BLADES

By Harold J. Schum and Warren J. Whitney

SUMMARY

A single-stage modification of the turbine from a Mark 25 torpedo power plant was investigated to determine the performance with two nozzle designs in combination with special rotor blades having a 20° inlet angle. The performance is presented in terms of blade, rotor, and brake efficiency as a function of blade-jet speed ratio for pressure ratios of 8, 15 (design), and 20.

The blade efficiency with the nozzle having circular passages (K) was equal to or higher than that with the nozzle having rectangular passages (J) for all pressure ratios and speeds investigated. The maximum blade efficiency of 0.571 was obtained with nozzle K at a pressure ratio of 8 and a blade-jet speed ratio of 0.296. The difference in blade efficiency was negligible at a pressure ratio of 8 at the low speeds; the maximum difference was 0.040 at a pressure ratio of 20 and a blade-jet speed ratio of 0.260.

The blade efficiency of the unit with nozzles J and K was compared with the blade efficiencies obtained with four other nozzle designs previously investigated in combination with the 20°-inlet-angle rotor blades. The blade efficiency with nozzle J was relatively low, whereas the efficiency with nozzle K was equal to or higher than those with the other nozzles over the range of speeds at pressure ratios of 15 and 20. The maximum difference in blade efficiency ascribable to the nozzle designs was 0.040.

[Redacted]

INTRODUCTION

The performance of the turbine from the Mark 25 aerial-torpedo power plant was investigated at the NACA Lewis laboratory at the request of the Bureau of Ordnance, Department of the Navy. Because of the small blade heights and the impracticability of obtaining measurements within the turbine, the only method of evaluating characteristics is a comparative study of over-all performance with various nozzle and rotor configurations. Previous investigations with various nozzle and blade designs are reported in references 1 to 4.

The nozzle-design studies have been continued with two additional nozzles arbitrarily designated J and K. Both nozzles had smaller port cross-sectional areas than those nozzles of similar design previously investigated. The performance of a single-stage unit with nozzles J and K and special 0.45-inch rotor blades is reported in reference 5. In the investigation reported herein, nozzles J and K were operated in combination with rotor blades of standard length (0.40 in.) but an inlet angle of 20° instead of the standard 17° inlet angle.

The performance of the single-stage turbine was determined for constant inlet temperature and pressure of 1000° F and 95 pounds per square inch gage. The turbine was operated at pressure ratios of 8, 15 (design), and 20 over a speed range of 6000 to 18,000 rpm. Indicated turbine power output was corrected for mechanical losses to determine rotor efficiency and for mechanical and windage losses to determine blade efficiency.

APPARATUS AND METHODS

The Mark 25 aerial-torpedo power plant described in reference 1 consists of a two-stage counterrotating impulse turbine employing a 90°-nozzle-arc gas admission. The unit was modified to operate as a single-stage turbine for the investigation reported herein, the apparatus and instrumentation being the same as that described in reference 2 with the exception of the rotor and the nozzles. The rotor blades investigated have an inlet angle of 20° instead of the standard 17°.

Characteristics of nozzles J and K and nozzles A, E, H, and I previously investigated are presented in the following table:

| Nozzle | Number of ports | Port-inlet configuration | Cross-sectional shape of port | Total measured throat area (sq. in.) | Measured expansion ratio |
|--------|-----------------|--------------------------|-------------------------------|--------------------------------------|--------------------------|
| A | 9 | Rounded | Rectangular | 0.183 | 1.47 |
| E | 9 | Rounded | Circular | .193 | 1.00 |
| H | 9 | Sharp-edged | Rectangular | .226 | 1.12 |
| I | 9 | Sharp-edged | Rectangular | .217 | 1.20 |
| J | 9 | Sharp-edged | Rectangular | .191 | 1.11 |
| K | 8 | Sharp-edged | Circular | .153 | 1.16 |

Nozzles J and K are shown in figure 1 and are described in reference 5. Nozzle J was run with a 0.030-inch nozzle-rotor axial clearance; nozzle K was operated at 0.040-inch clearance. Reference 3, however, indicates no effect on turbine performance for this increment in clearance.

The precision of the observed measurements is estimated to be within the following limits:

| | |
|--|-------|
| Air flow, percent | ±1.50 |
| Torque, ft-lb | ±0.15 |
| Dynamometer speed, rpm | ±5 |
| Inlet-gas temperature, percent | ±0.25 |
| Inlet-gas pressure, percent | ±0.50 |
| Pressure, in. Hg absolute | ±0.05 |

The calculation methods are given in references 1 and 2.

RESULTS AND DISCUSSION

The efficiency data of the Mark 25 turbine modified to operate as a single-stage unit with nozzles J and K and special 20°-inlet-angle blades are summarized in tables I and II, respectively.

Brake efficiency and rotor efficiency are shown in figures 2 and 3, respectively, for the two nozzle-rotor configurations. At a pressure ratio of 8, the brake efficiencies with the two nozzles were practically equal over the speed range, as were the rotor efficiencies; the maximum efficiency difference is less than 0.010. At pressure ratios of 15 and 20, however, both brake and rotor efficiencies for nozzle K were higher than those obtained for nozzle J over the operating range.

The blade efficiency with the two nozzles is shown in figure 4. Blade efficiency was considered a better criterion of performance for a given nozzle-blade combination because the effects of mechanical friction and windage are eliminated. A maximum blade efficiency of 0.571 was obtained with nozzle K at a pressure ratio of 8 and a blade-jet speed ratio of 0.296 (fig. 4(a)). The blade efficiency of nozzle K was equal to or higher than that obtained for nozzle J over the range of operating variables investigated. These results show a reversal of the trend indicated in reference 5. The explanation of this reversal is beyond the scope of this report. The maximum difference in blade efficiency was 0.040 at a pressure ratio of 20 and a blade-jet speed ratio of 0.260 (fig. 4(c)), the difference being negligible at a pressure ratio of 8 and the low speeds (fig. 4(a)).

For all pressure ratios and all nozzle-rotor combinations investigated, efficiency continuously increased with blade-jet speed ratio. It was impossible to obtain a peak efficiency because turbine speed was limited to the design value of 18,000 rpm. Efficiency decreased with an increase in pressure ratio for any given blade-jet speed ratio and for all nozzle-rotor combinations. Blade-horsepower output is defined as brake-horsepower output plus windage and mechanical losses. Because windage losses are a function of rotor and blade configuration and mechanical losses are dependent on the reduction-gear and bearing friction, these losses are for the most part independent of nozzle design. The horsepower necessary to overcome these losses for any specified inlet condition, blade-jet speed ratio, and pressure ratio is the same for both nozzles J and K. Crediting the turbine output with this incremental horsepower does not result in equal increments of efficiency (blade minus brake) for the two nozzles because the observed weight flow for nozzle K is approximately 77 percent of that for nozzle J at corresponding flow conditions; and efficiency is an expression of horsepower per pound of air flow at the specified operating conditions. This effect is noticeable when figures 2 and 4 are compared. Although the maximum brake efficiencies are substantially equal for the two nozzles at a pressure ratio of 8 (fig. 2(a)), the maximum blade efficiencies at corresponding conditions (fig. 4(a)) differ by 0.020.

The blade efficiencies of the rotor having 20°-inlet-angle blades with nozzles J and K are compared (fig. 5) with results previously obtained at corresponding operating conditions with nozzles A, E, H, and I (reference 4). The maximum variation in efficiency was 0.040. The blade efficiency obtained with nozzle J was generally lower than that obtained with the other nozzles. The blade efficiency for nozzle K was equal to or higher than that

for the other nozzles at pressure ratios of 15 and 20 over the speed range investigated. At a pressure ratio of 8, the blade efficiency of nozzle K was exceeded by that obtained for nozzles I and A.

SUMMARY OF RESULTS

An investigation of a single-stage modification of the turbine from a Mark 25 aerial-torpedo power plant with two nozzle designs and 20°-inlet-angle blades produced the following results:

1. The blade efficiency of the unit with nozzle K was equal to or higher than that obtained with nozzle J over the range of operating variables investigated. The maximum blade efficiency of 0.570 was obtained with nozzle K at a pressure ratio of 8 and a blade-jet speed ratio of 0.296.
2. The difference in blade efficiency was negligible at a pressure ratio of 8 and the low speeds. The maximum difference in blade efficiency was 0.040 at a pressure ratio of 20 and a blade-jet speed ratio of 0.260.
3. The blade efficiency for nozzle J was relatively low compared with the nozzle designs previously investigated. At pressure ratios of 15 and 20, the blade efficiency for nozzle K was equal to or higher than those obtained with other nozzles.
4. The maximum difference in blade efficiency ascribable to the six nozzle designs in combination with the 20°-inlet-angle rotor blade was 0.040.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, May 10, 1949.

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2. Hoyt, Jack W.: Investigation of Single-Stage Modified Turbine of Mark 25 Torpedo Power Plant. NACA RM SE7L15, Bur. Ord., 1948.
3. Hoyt, Jack W., and Kottas, Harry: Effect of Turbine Axial Nozzle-Wheel Clearance on Performance of Mark 25 Torpedo Power Plant. NACA RM SE8B04, Bur. Ord., 1948.
4. Schum, Harold J., and Hoyt, Jack W.: Effect of First-Stage Blade Design on Performance of Mark 25 Torpedo Power Plant. NACA RM SE9G20, Bur. Ord., 1949.
5. Schum, Harold J., and Whitney, Warren J.: Performance of Single-Stage Turbine of Mark 25 Torpedo Power Plant with Two Special Nozzles. I - Efficiency with 0.45-Inch Rotor Blades. NACA RM SE9G20a, Bur. Ord., 1949.

TABLE I - EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED TURBINE WITH NOZZLE J AND 20°-INLET-ANGLE BLADES

[Inlet temperature, 1000° F; inlet pressure, 95 lb/sq in. gage]

| Pres- sure ratio | Air weight flow (lb/hr) | Fuel- air ratio | Horsepower available from 1sen- tropic expansion | Turbine speed (rpm) | Brake- horse- power | Blade- jet speed ratio | Gas den- sity in turbine case (lb/cu ft) | Brake effi- ciency | Rotor effi- ciency | Blade effi- ciency |
|------------------------|----------------------------------|-----------------------|--|---------------------------|---------------------------|---------------------------------|--|--------------------------|--------------------------|--------------------------|
| 8 | 935.0 | 0.0136 | 59.81 | 6,029 | 14.92 | 0.0977 | 0.0323 | 0.249 | 0.255 | 0.257 |
| | 934.2 | .0136 | 59.76 | 8,112 | 18.87 | .1315 | .0328 | .316 | .326 | .329 |
| | 934.2 | .0136 | 59.76 | 10,135 | 22.21 | .1643 | .0331 | .372 | .387 | .393 |
| | 934.2 | .0136 | 59.76 | 12,138 | 24.80 | .1967 | .0330 | .415 | .435 | .443 |
| | 934.2 | .0136 | 59.76 | 14,181 | 26.82 | .2298 | .0327 | .449 | .474 | .487 |
| | 933.3 | .0135 | 59.70 | 16,204 | 28.36 | .2626 | .0324 | .475 | .505 | .527 |
| | 933.3 | .0135 | 59.70 | 18,247 | 29.10 | .2957 | .0320 | .487 | .523 | .554 |
| | | | | | | | | | | |
| 15 | 930.7 | 0.0137 | 71.88 | 6,069 | 15.52 | 0.0896 | 0.0168 | 0.216 | 0.220 | 0.222 |
| | 930.7 | .0137 | 71.88 | 8,112 | 19.73 | .1198 | .0170 | .275 | .283 | .285 |
| | 930.7 | .0137 | 71.88 | 10,095 | 23.15 | .1491 | .0168 | .322 | .335 | .338 |
| | 930.7 | .0137 | 71.88 | 12,158 | 26.24 | .1795 | .0166 | .365 | .382 | .385 |
| | 930.7 | .0137 | 71.88 | 14,181 | 28.65 | .2094 | .0167 | .399 | .420 | .424 |
| | 929.9 | .0136 | 71.81 | 16,184 | 30.56 | .2389 | .0165 | .426 | .451 | .459 |
| | 930.7 | .0136 | 71.87 | 18,207 | 31.98 | .2688 | .0165 | .445 | .474 | .487 |
| | | | | | | | | | | |
| 20 | 930.7 | 0.0138 | 76.86 | 6,089 | 15.55 | 0.0870 | 0.0139 | 0.202 | 0.207 | 0.208 |
| | 930.7 | .0138 | 76.86 | 8,092 | 19.52 | .1156 | .0142 | .254 | .262 | .264 |
| | 930.7 | .0138 | 76.86 | 10,115 | 23.17 | .1445 | .0139 | .302 | .313 | .316 |
| | 930.7 | .0138 | 76.86 | 12,138 | 26.36 | .1733 | .0136 | .343 | .359 | .361 |
| | 930.7 | .0137 | 76.85 | 14,161 | 28.93 | .2022 | .0137 | .376 | .396 | .399 |
| | 930.7 | .0137 | 76.85 | 16,194 | 31.22 | .2313 | .0136 | .406 | .430 | .436 |
| | 930.7 | .0137 | 76.84 | 18,207 | 32.70 | .2600 | .0136 | .426 | .453 | .463 |
| | | | | | | | | | | |

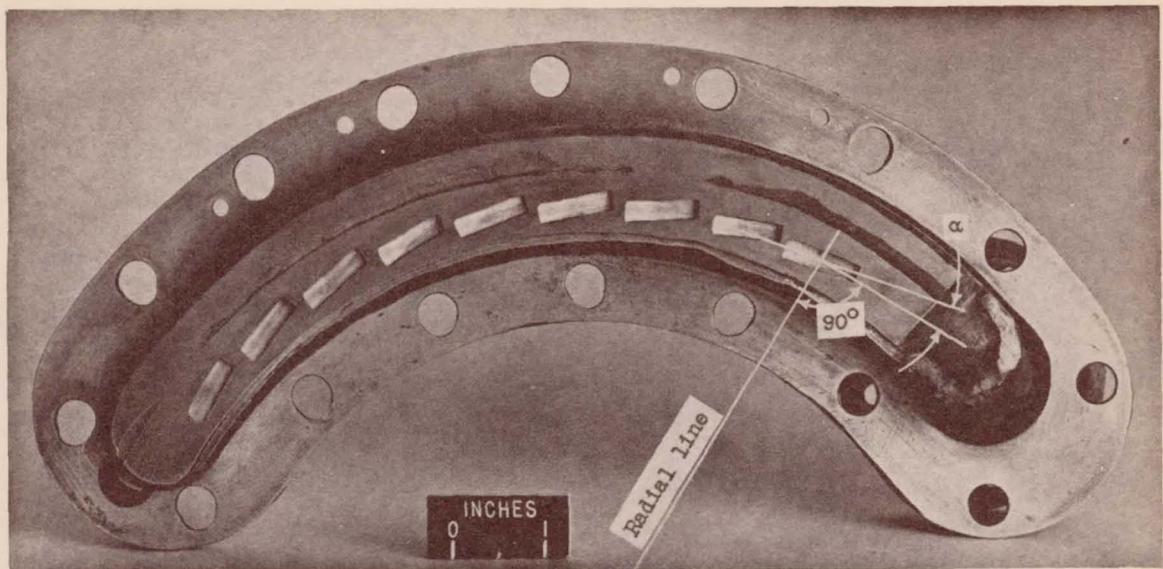


TABLE II - EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED TURBINE WITH NOZZLE K AND 20°-INLET-ANGLE BLADES

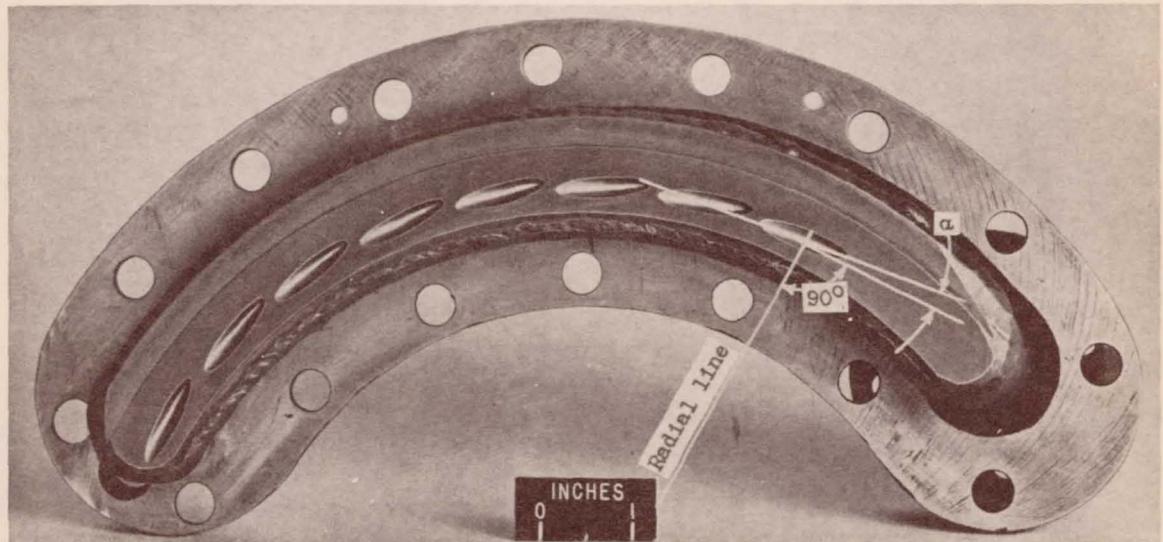
[Inlet temperature, 1000° F; inlet pressure, 95 lb/sq in. gage]

| Pressure ratio | Air weight flow (lb/hr) | Fuel-air ratio | Horsepower available from isentropic expansion | Turbine speed (rpm) | Brake horsepower ratio | Blade-jet speed ratio | Gas density in turbine case (lb/cu ft) | Brake efficiency | Rotor efficiency | Blade efficiency |
|----------------|-------------------------|----------------|--|---------------------|------------------------|-----------------------|--|------------------|------------------|------------------|
| 8 | 724.8 | 0.0142 | 46.41 | 6,049 | 11.44 | 0.0980 | 0.0329 | 0.247 | 0.253 | 0.256 |
| | 724.8 | .0142 | 46.41 | 8,092 | 14.40 | .1311 | .0330 | .310 | .323 | .328 |
| | 724.8 | .0141 | 46.40 | 10,115 | 17.13 | .1639 | .0342 | .369 | .389 | .396 |
| | 724.8 | .0142 | 46.41 | 12,158 | 19.43 | .1970 | .0349 | .419 | .445 | .456 |
| | 724.1 | .0141 | 46.35 | 14,201 | 20.78 | .2301 | .0354 | .448 | .481 | .500 |
| | 724.1 | .0141 | 46.35 | 16,184 | 21.92 | .2623 | .0349 | .473 | .512 | .542 |
| | 723.4 | .0141 | 46.31 | 18,247 | 22.31 | .2957 | .0347 | .482 | .528 | .571 |
| | | | | | | | | | | |
| 15 | 724.8 | 0.0142 | 56.02 | 6,089 | 12.44 | 0.0899 | 0.0180 | 0.222 | 0.228 | 0.230 |
| | 724.8 | .0142 | 56.02 | 8,092 | 15.76 | .1195 | .0181 | .281 | .292 | .295 |
| | 724.8 | .0142 | 56.01 | 10,166 | 18.83 | .1501 | .0183 | .336 | .353 | .357 |
| | 724.8 | .0142 | 56.01 | 12,118 | 21.36 | .1789 | .0187 | .381 | .403 | .407 |
| | 724.8 | .0142 | 56.01 | 14,161 | 23.47 | .2091 | .0190 | .419 | .446 | .453 |
| | 724.8 | .0142 | 56.02 | 16,224 | 25.13 | .2396 | .0191 | .449 | .481 | .493 |
| | 724.8 | .0142 | 56.01 | 18,207 | 26.28 | .2688 | .0191 | .469 | .507 | .526 |
| | | | | | | | | | | |
| 20 | 723.4 | 0.0141 | 59.76 | 6,069 | 12.48 | 0.0867 | 0.0136 | 0.209 | 0.214 | 0.216 |
| | 722.8 | .0141 | 59.71 | 8,092 | 15.92 | .1156 | .0138 | .267 | .277 | .279 |
| | 722.8 | .0141 | 59.71 | 10,115 | 19.00 | .1445 | .0140 | .318 | .333 | .337 |
| | 722.8 | .0141 | 59.71 | 12,138 | 21.68 | .1733 | .0140 | .363 | .383 | .386 |
| | 722.8 | .0141 | 59.71 | 14,201 | 23.91 | .2028 | .0142 | .400 | .426 | .430 |
| | 722.8 | .0141 | 59.71 | 16,184 | 25.87 | .2311 | .0143 | .433 | .464 | .472 |
| | 722.8 | .0141 | 59.71 | 18,227 | 27.15 | .2603 | .0143 | .455 | .490 | .503 |
| | | | | | | | | | | |



(a) Nozzle J; angle of intangency α , 9° .

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(b) Nozzle K; angle of intangency α , 6° .
Figure 1. - Nozzle assembly showing outlet side.

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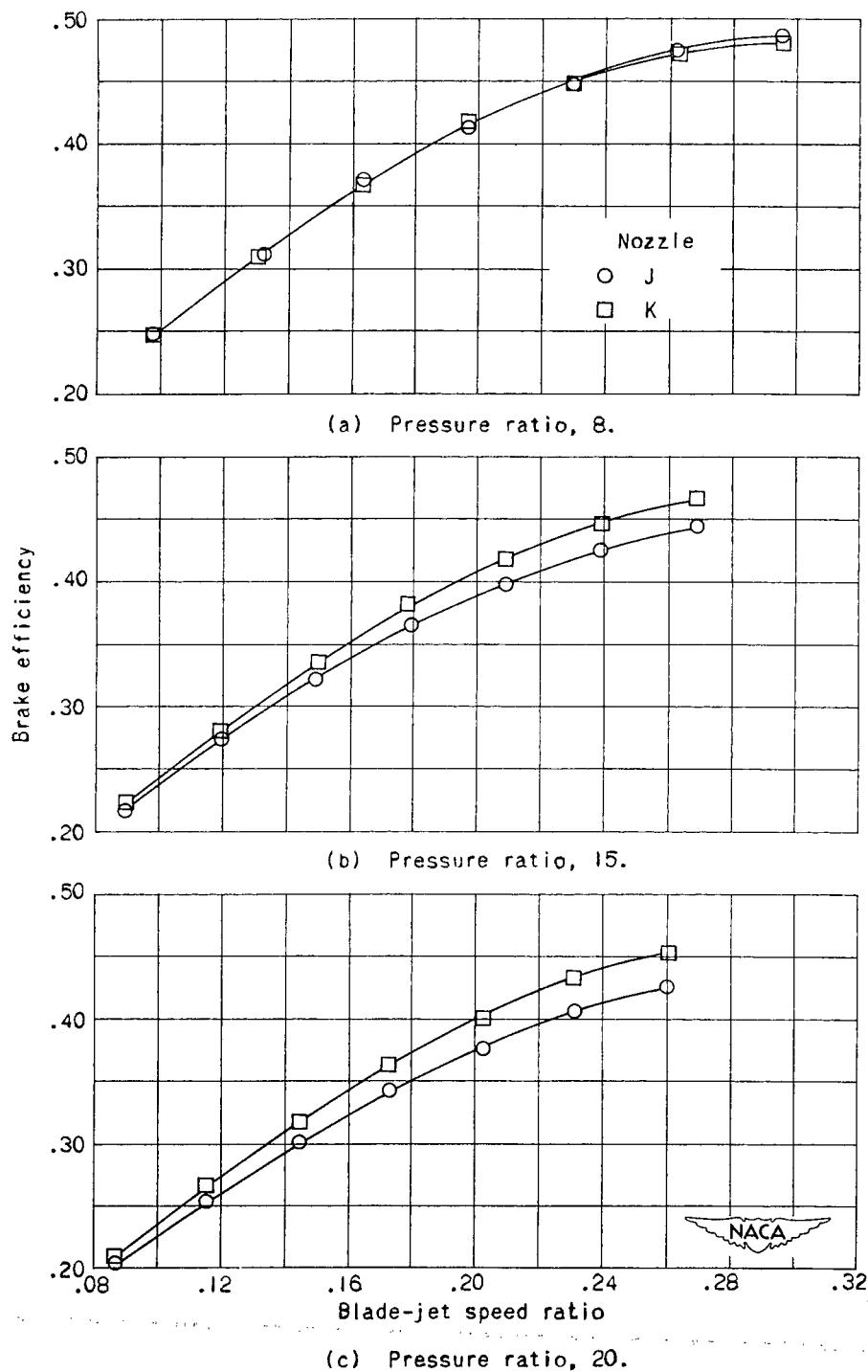


Figure 2. - Variation of brake efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzles J and K in combination with special 20°-inlet-angle blades.

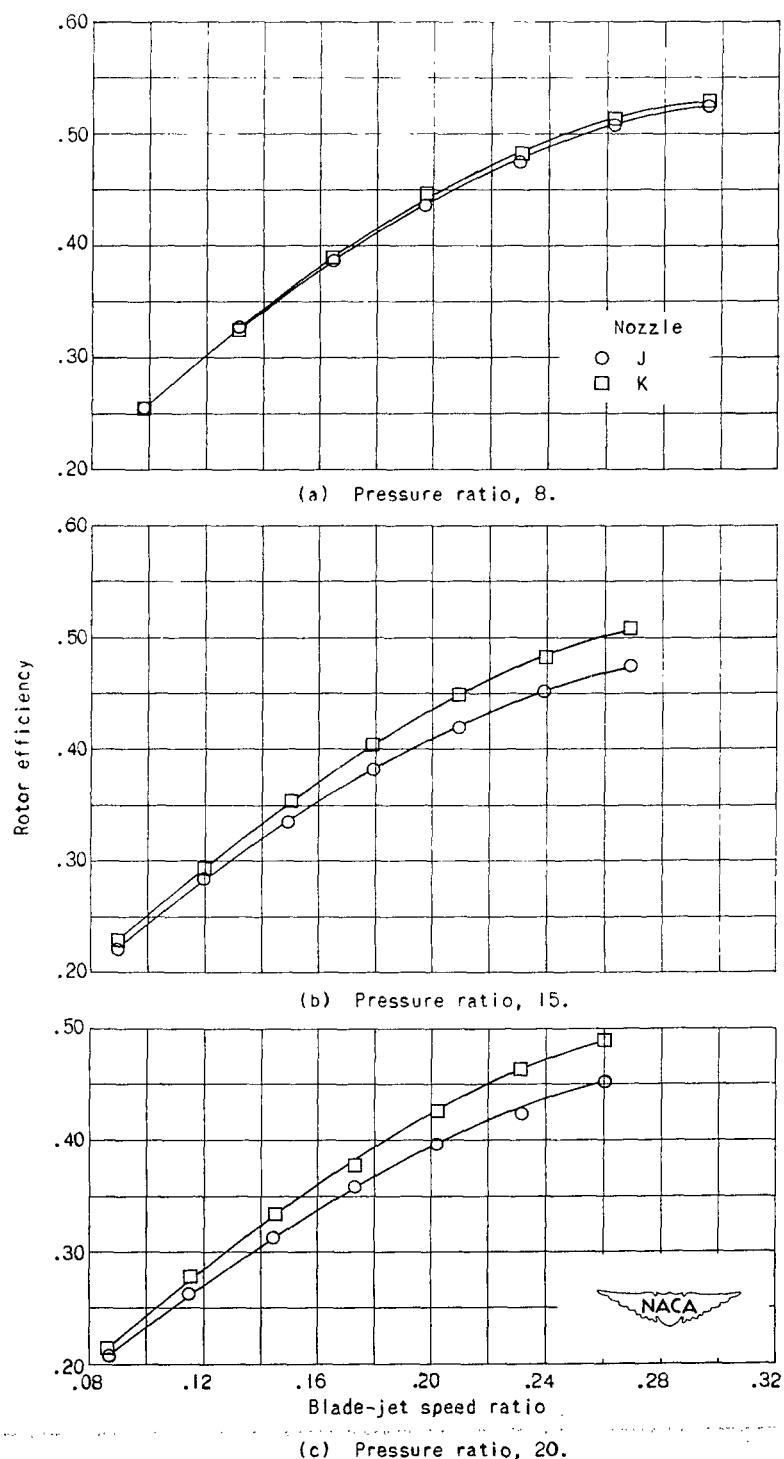


Figure 3. - Variation of rotor efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzles J and K in combination with special 20°-inlet-angle blades.

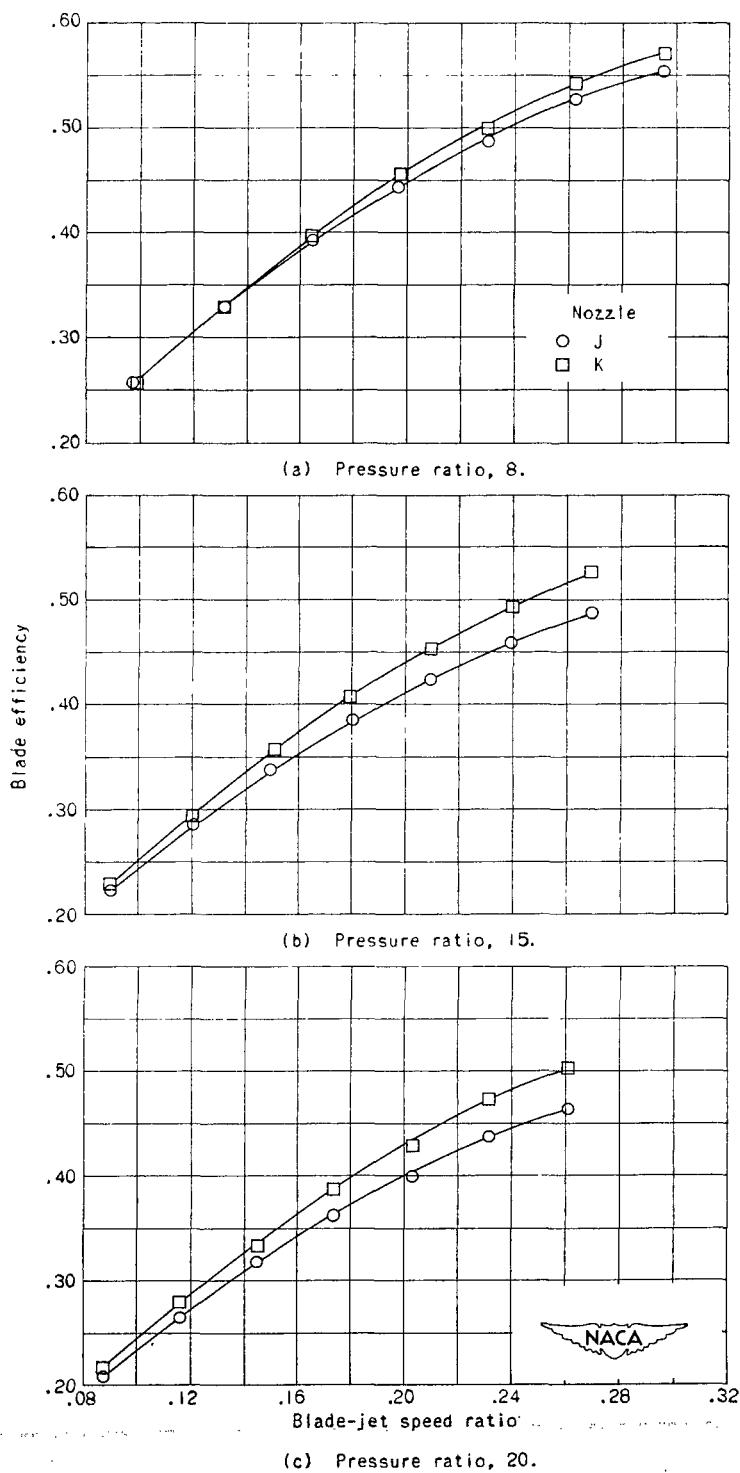


Figure 4. - Variation of blade efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzles J and K in combination with special 20°-inlet-angle blades.

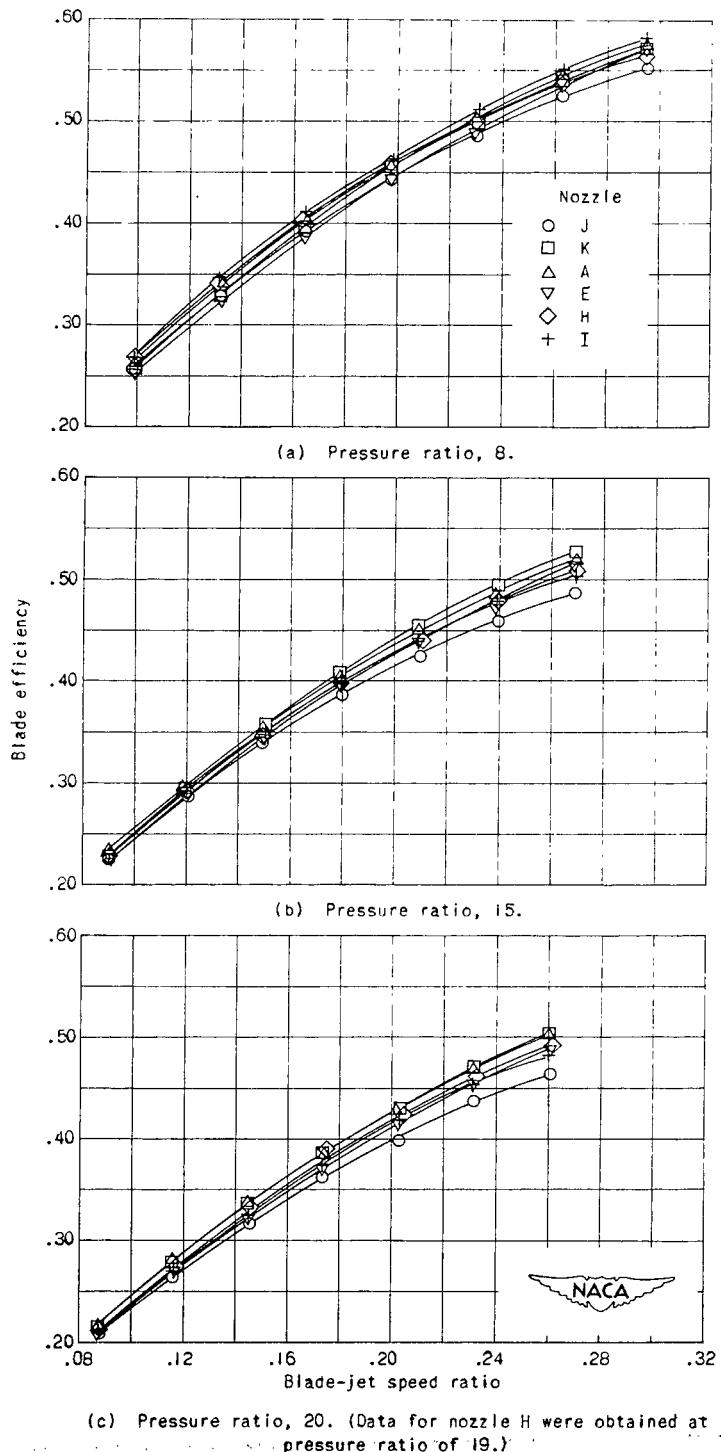


Figure 5. - Variation of blade efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzles J, K, A, E, H, and I in combination with special 20°-inlet-angle blades. (Data for nozzles A, E, H, and I obtained from reference 4.)

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